Deep Space Power 2018

Solar/Battery Power Architectures for Missions to Jupiter and Beyond

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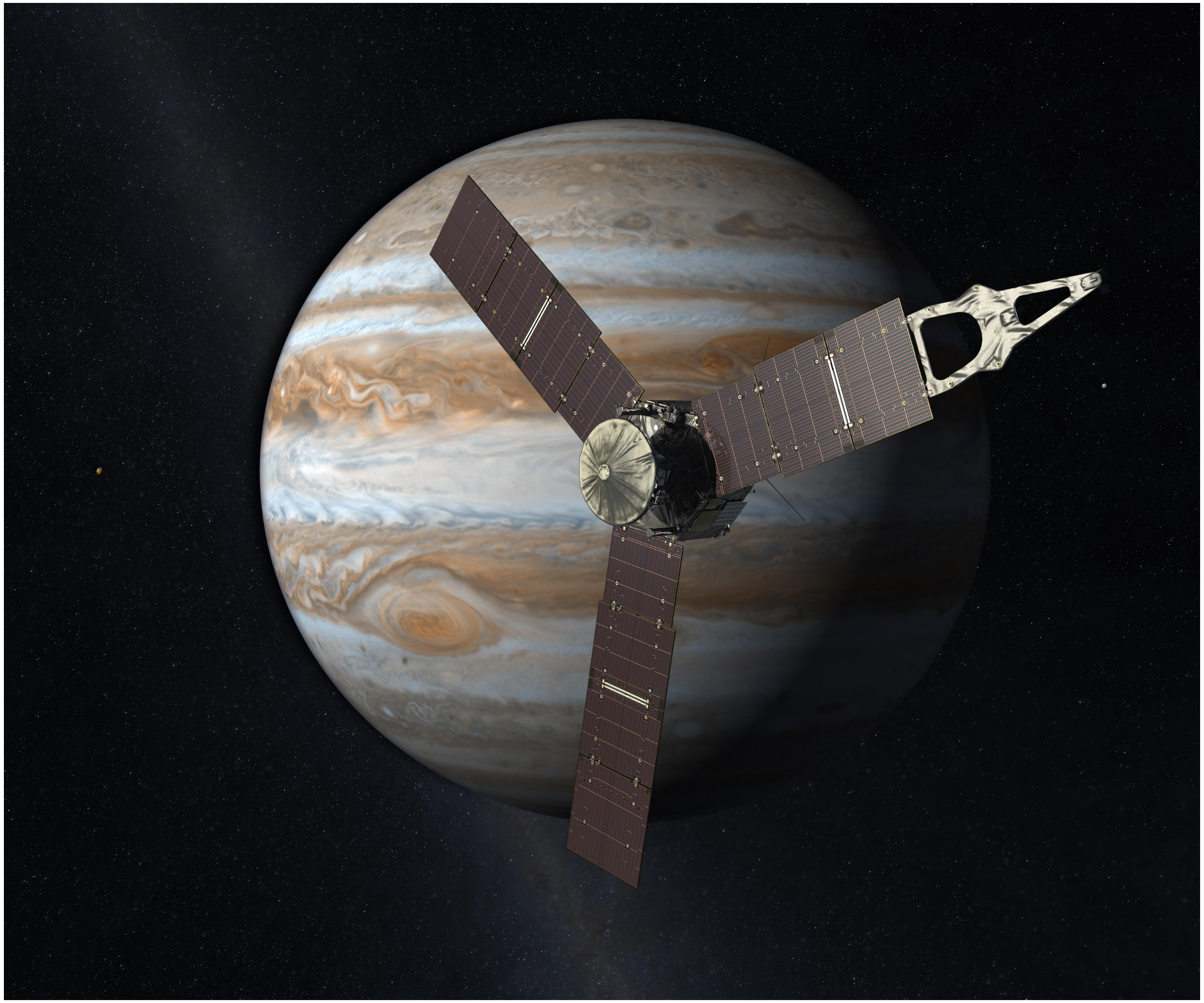
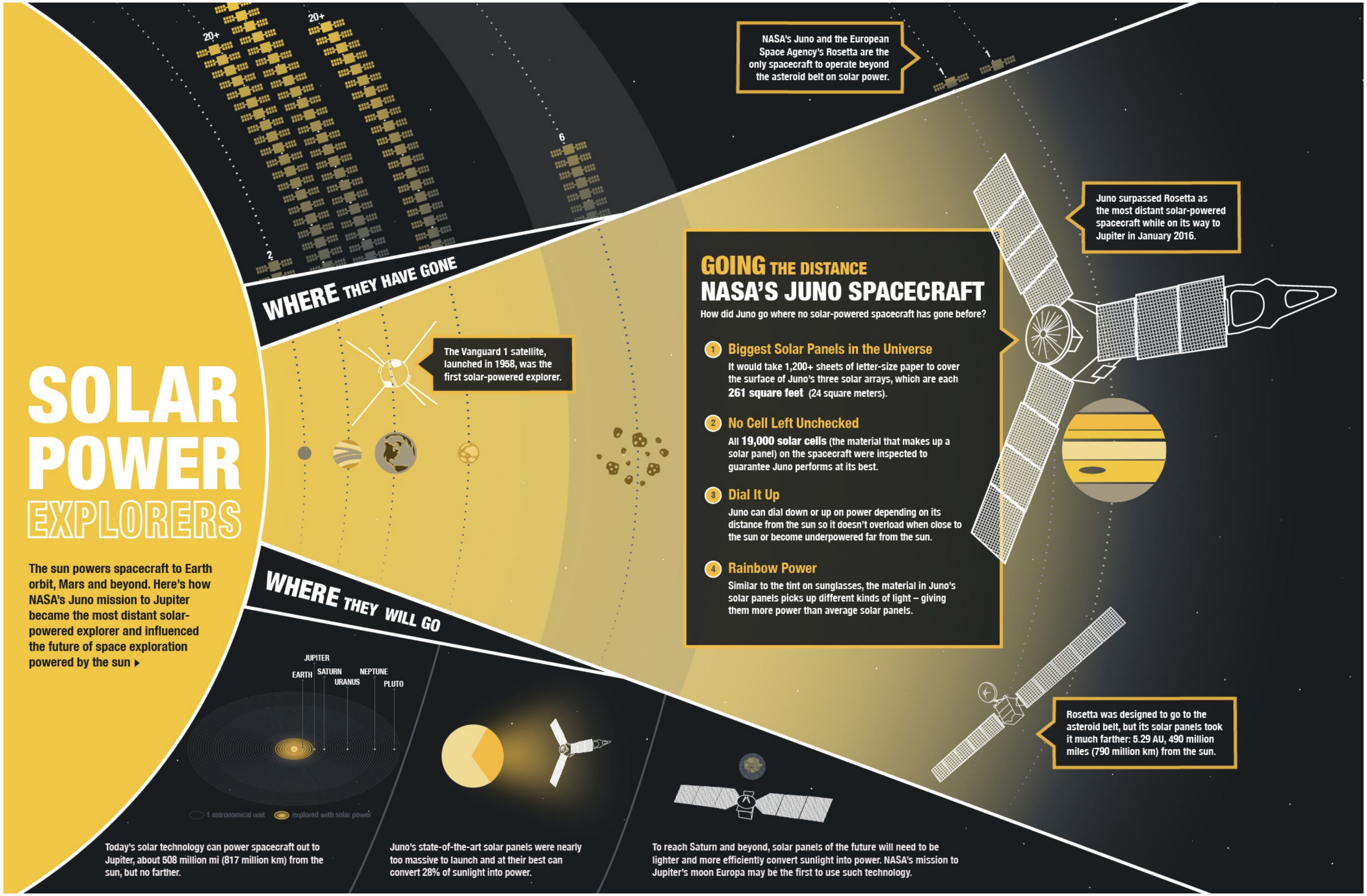
Juno at Jupiter (Artist’s concept)



Credits: NASA/JPL-Caltech/

Juno breaks solar distance record



Credits: NASA/JPL-Caltech/

Outline

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- Influence of Mission Design
- Science Instrument Influence
- Thermal Design Approach
- Solar Array and Battery Performance
- Trades Between RPS and Solar
- Juno, Europa Clipper Case Studies
- Overall System Performance Evaluation
- Future Technology Opportunities
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Deep Space Mission Power Source Consideration

- **Power System Trade Space**
  - Radioisotope Power System (MMRTG, eMMRTG, Next-Gen RTG Dynamic RPS)
  - Fission Power Source (Kilo-PWR)
  - Solar Array Technology (Rigid, Flexible, Concentration, LILT)
  - Energy Storage Technology (Primary, Secondary, Thermal)
- **Science Target**
  - Mars (1.6 AU)
  - Asteroid (2.7 – 3.3 AU)
  - Jovian Moon (5 – 5.5 AU)
  - Saturn Moon (9.1 – 10 AU)
  - Neptune and Triton (30.1 AU)

Power Source selection is an End-to-End System Level Trade.

Influence of Mission Design

- Mission duration vs. solar range
  - Duration of mission affects the RPS option (2% to 5% degradation per year)
  - Solar Array performance is dominated by solar range and radiation
  - Long Life Battery Technology
- Launch vehicle
  - Volume of the shroud to fit the stowed solar array
  - Doors in the shroud for RPS installation
- Trajectory
  - Direct vs. Gravity Assist (can save 4 years duration and inner solar system stress on the solar arrays)
  - Can the tour avoid the radiation? (e.g. Juno) (can save up to 20% of the power)
  - Solar range over the entire mission including science tour
  - Avoid eclipses (directly affects solar array temperature and sizes the battery)

The mission design could greatly influence the power source selection and enable solar power.

Science Instrument Definition

- Type of science instruments
  - Data volume (transmit downlink duty ratio)
  - EMI/EMC requirements (filter, grouting and control technique)
- Pointing, stability slew rate requirements
  - Reaction Wheel sizing
  - Thruster control
  - Fundamental frequency of the solar array can directly impact the mass
  - Flyby, orbiter affect the slew rate and stability
- Field of view
- Radar interference
- Plasma Science

The science definition has the potential to rule out solar or greatly increase the mass.

Thermal Design Approach

- Needs to be considered early in trade space
- It can make the difference between RPS and Solar
- Defines the minimum power required for the spacecraft
- The waste heat of the components needs to be used
- The temperature of the propellant can set the minimum power requirements (can affect the minimum power by 100W)
- Thermal design needs to consider fluid loops and heat pipes to reduce the electrical power requirements (can save 200W)
- The temperature range of the solar array would affect the operating point and power control architecture

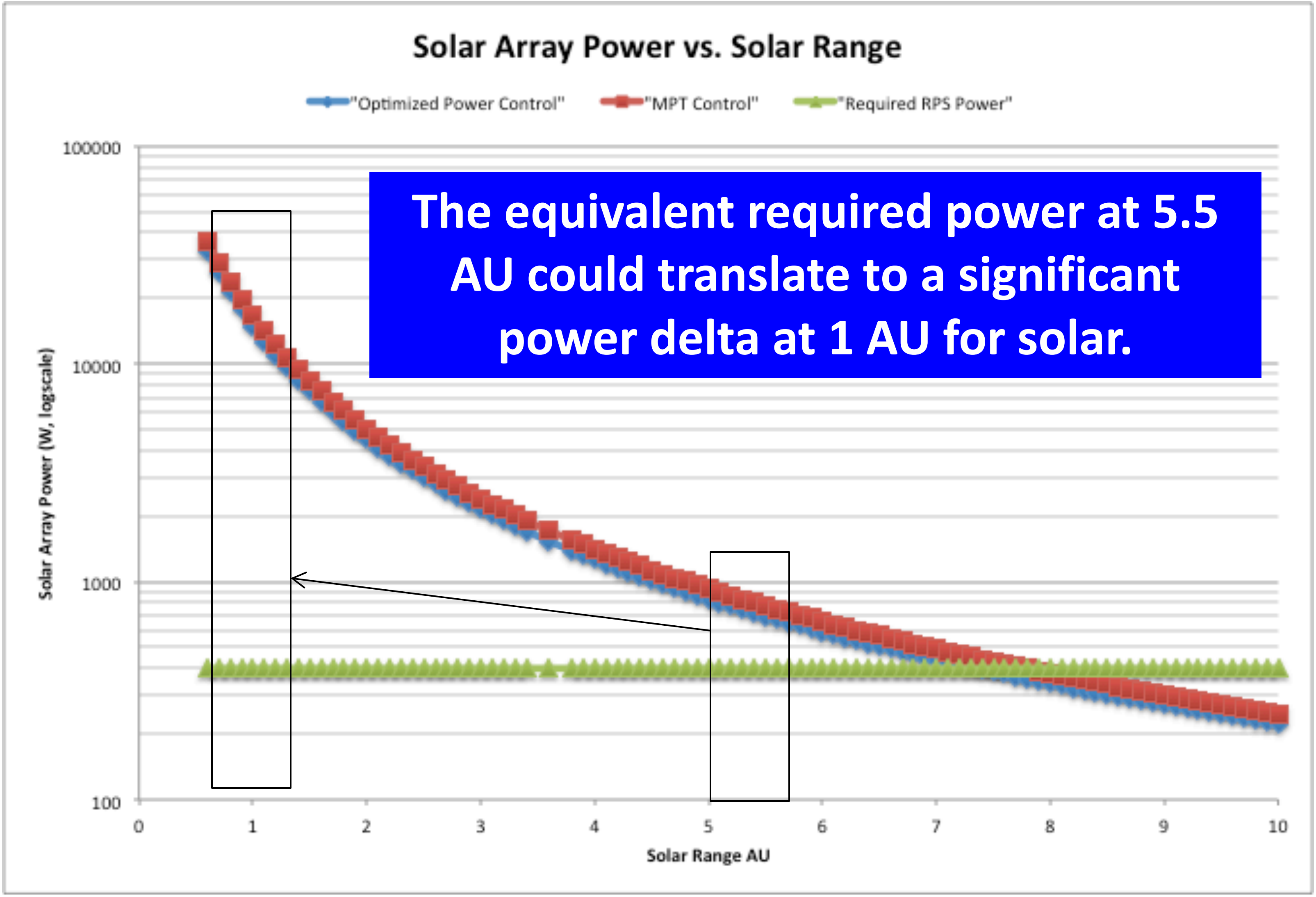
The thermal design could swing the trade for power source selection.

Solar Array Performance

- The solar array performance can be initially determined by manufactures cell specification
- Eventually cell testing for the end of mission environment needs to be used for solar array design
  - Includes Low Intensity Low Temperature (LILT) impact
  - Screening criteria can be determined from cell test data
- The complete mission design tour and solar range needs to be considered in the design of the array
  - Solar range and temperature will impact power control design and desired operating point
- The array design needs to be optimized for peak performance at the critical points in the mission which may not be the end of mission

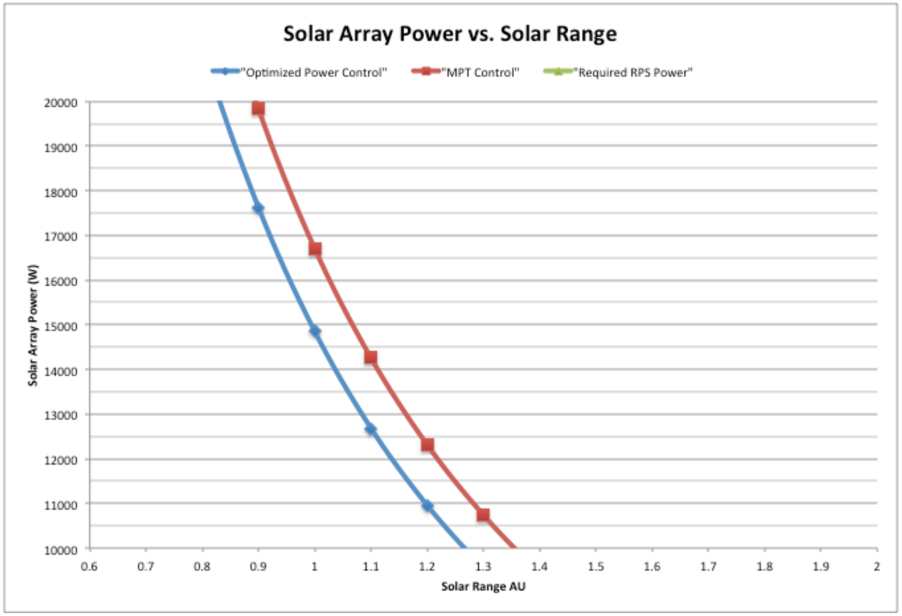
The solar array design is based on the cell test data in the specific environment

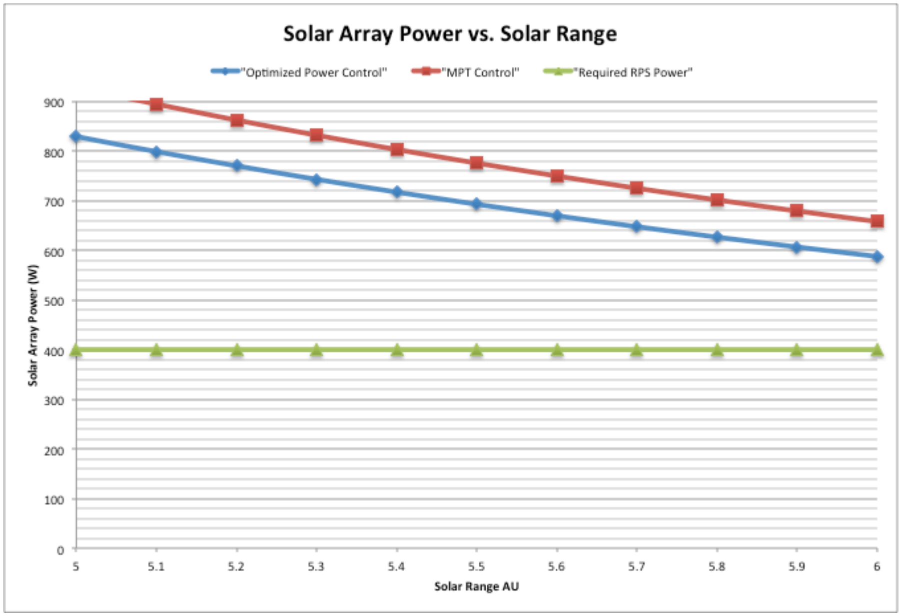
Solar Power vs. Range



Pre decisional: for information and discussion purposes only

RPS power vs. Solar Power (5.5 AU)





The required RPS power of 400 W at 5.5 AU and high radiation could translate to between a 14 and 17 kW at 1 AU solar array.

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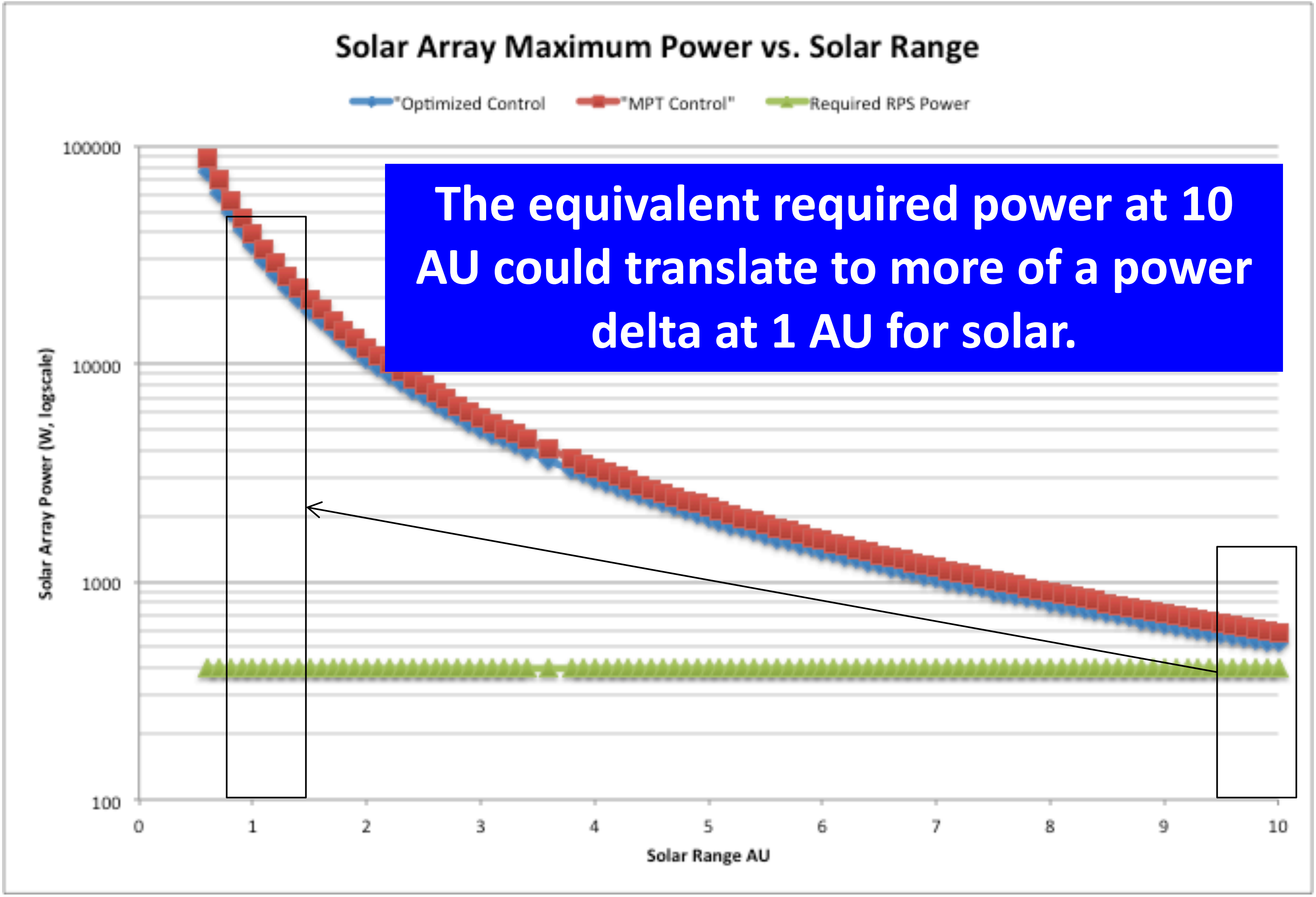
Solar Power vs. Range



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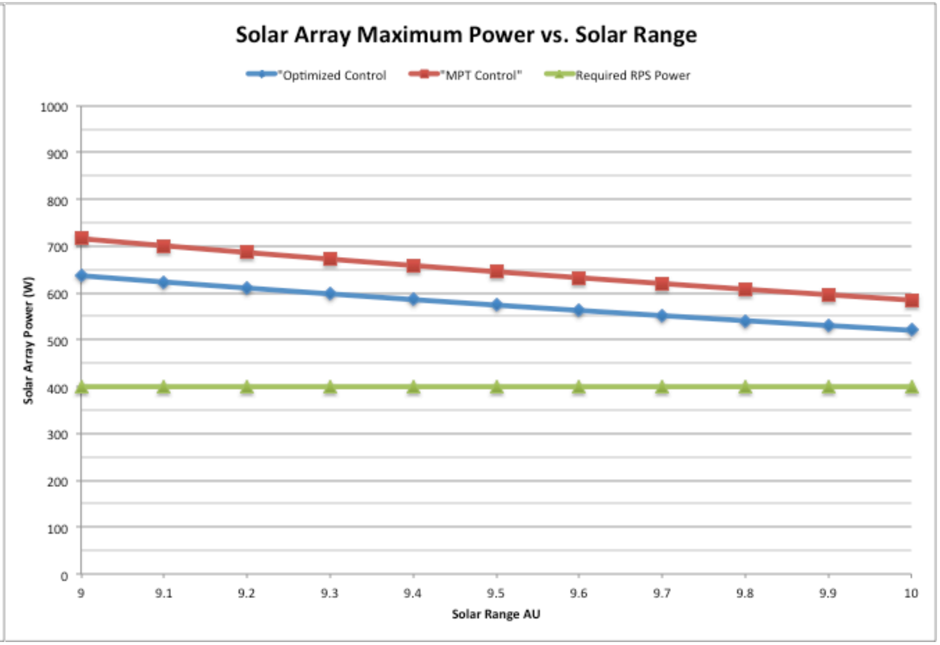
RPS power vs. Solar Power (10 AU)



The required RPS power of 400 W at 5.5 AU and high radiation could translate to between a 35 and 40 kW at 1 AU solar array.

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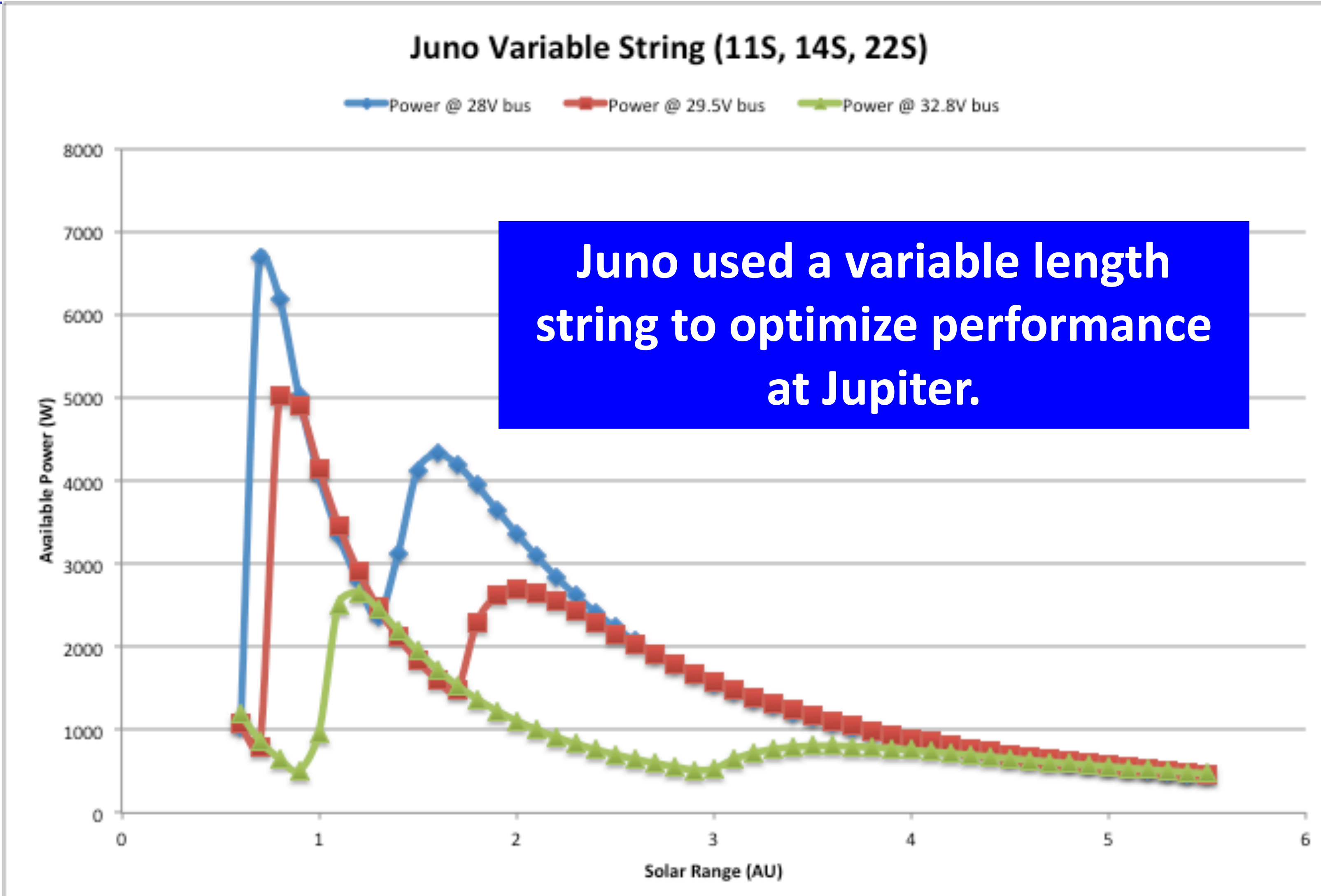
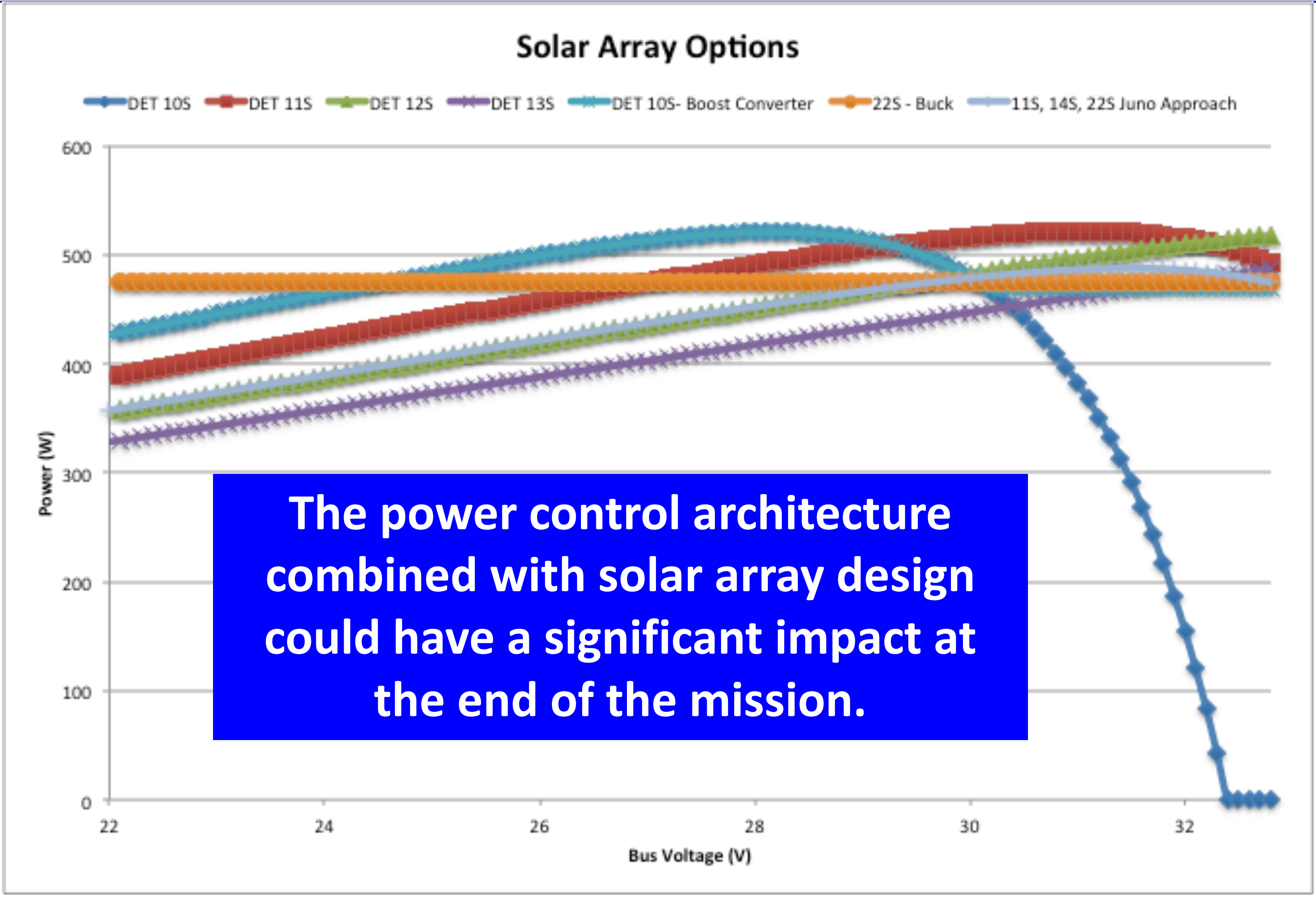
Variable string length approach

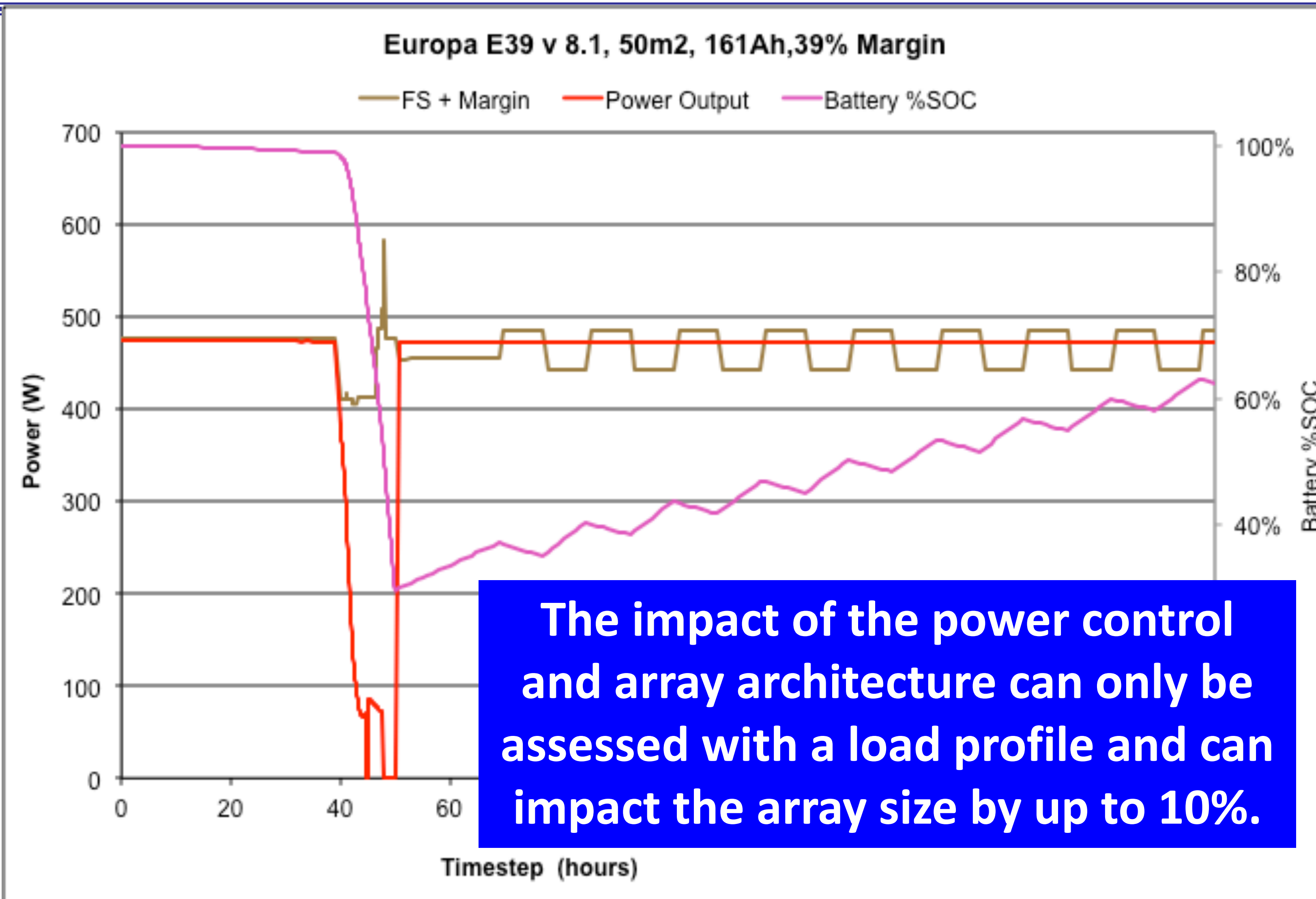


Power Control Optimization



The power control architecture combined with solar array design could have a significant impact at the end of the mission.

Load Profile Assessment



The impact of the power control and array architecture can only be assessed with a load profile and can impact the array size by up to 10%.

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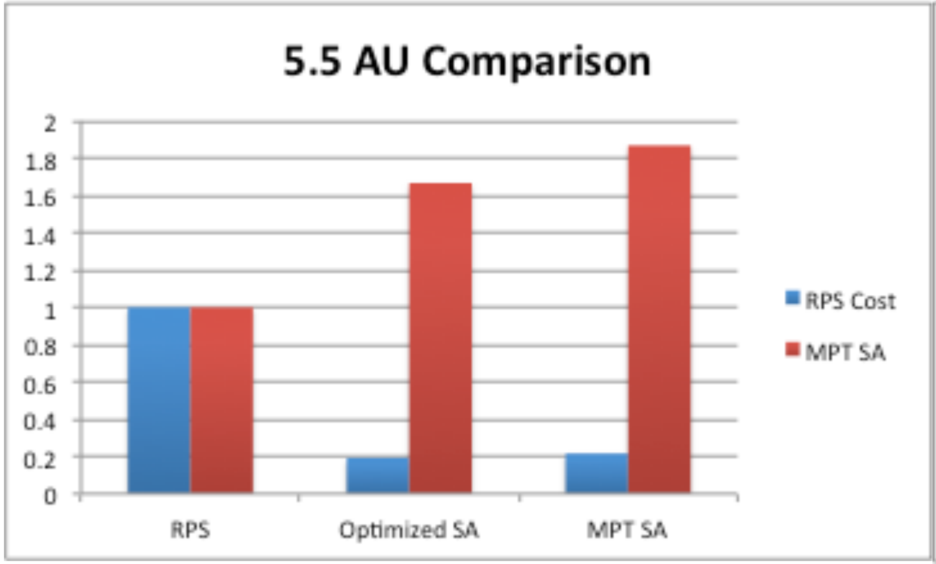
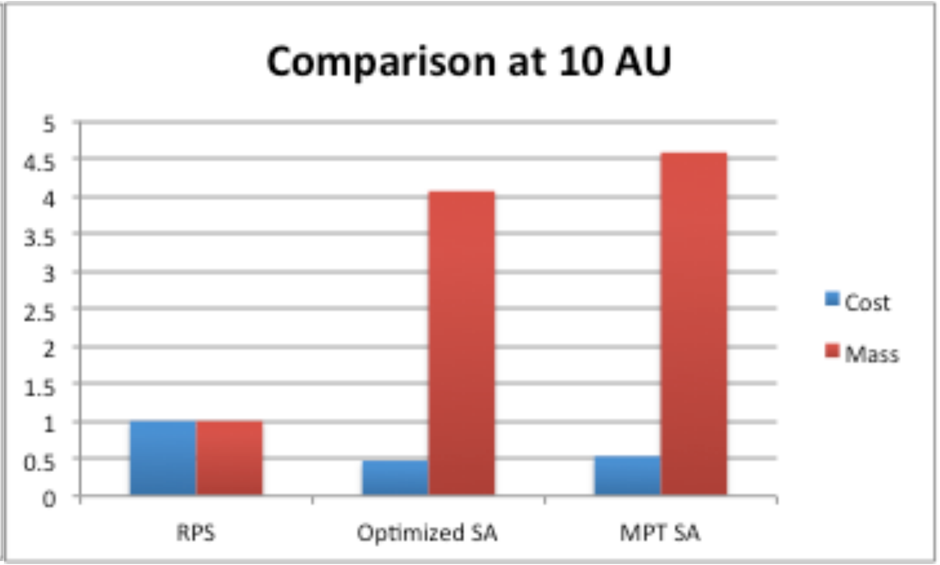
Overall System Performance Evaluation





Cost would be significantly lower (12%) for solar at 5.5 AU with a significant mass impact (67%).
Cost would be still lower for 10 AU (50%), but mass would be a factor of 4 greater.

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Juno and Europa Clipper Case studies

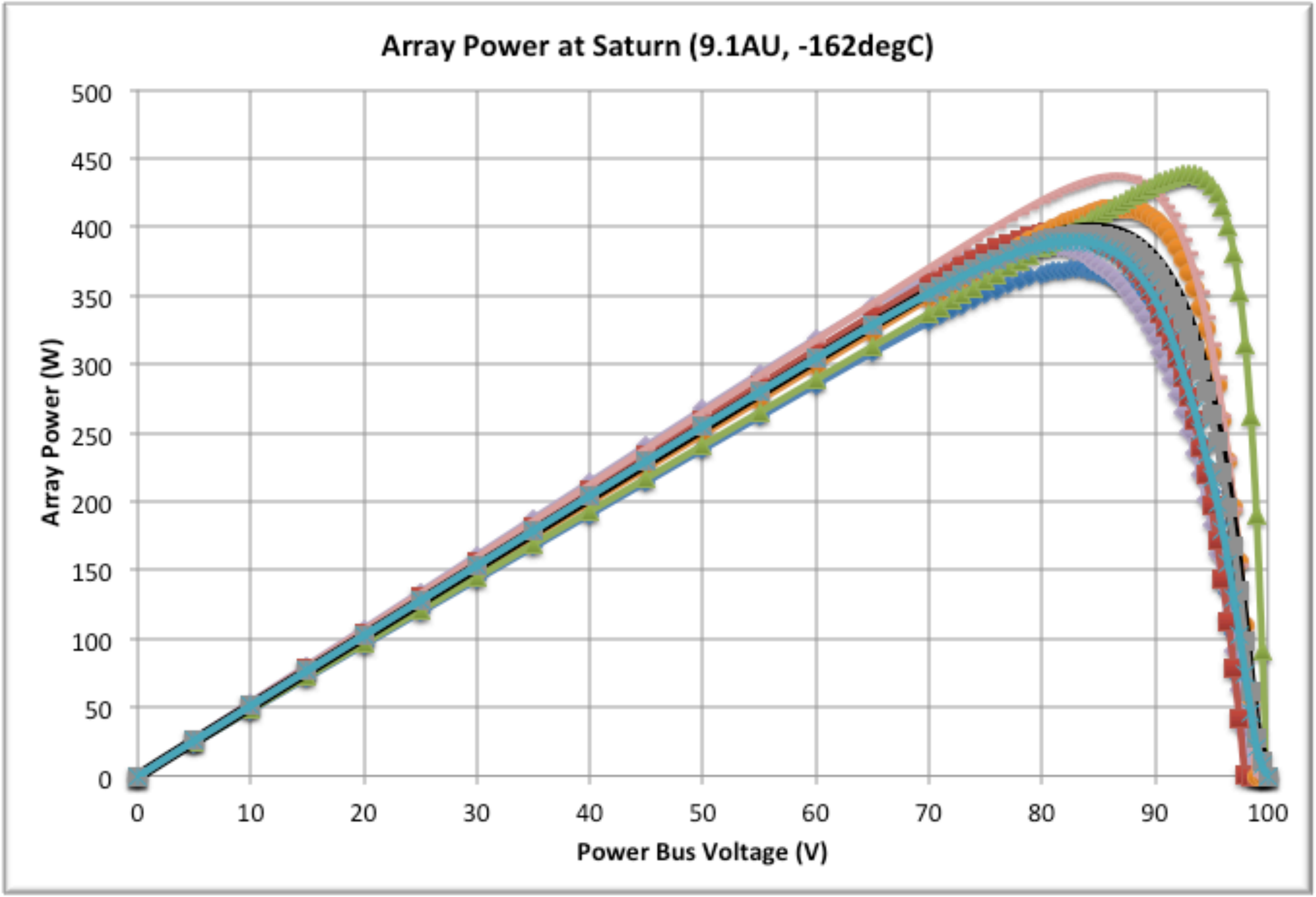
- Juno used variable string length array design, Li-Ion Battery and a low radiation orbit to make solar viable.
- Juno used a direct energy transfer architecture
- Europa Clipper baseline design uses a fluid loop thermal design, and a mission design that reduced radiation degradation in the array.
- Europa Clipper uses a down converter to get more power out of the array at a wider bus voltage range

Future Technology Opportunity

- LILT Optimization could improve the performance up to 10%, and reduce the screening uncertainty of 10%.
- Solar concentrating arrays could reduce mass with the additional pointing requirements, and improve LILT performance.
- Improve thermal management or lower temperature could reduce required power up to 300W.
- SEP optimization could reduce mass, and take advantage of high solar power early in the mission.

New technology in LILT optimization, array design, and thermal management could push solar to deeper space science targets.

LILT Optimized Solar Array



Summary

- The power source selection is an end-to-end system level trade.
- The mission design could greatly influence the power source selection, and enable solar power.
- The science definition has the potential to rule out solar or greatly increase the mass.
- The thermal design could swing the trade for the power source selection.
- The solar array design is based on cell test data in the specific environment.
- New technology in LILT optimization, array design, and thermal management could push solar to deeper space science targets.

ACKNOWLEDGMENT

- **I would like to thank the Europa Power Subsystem team for support with example case studies at the system level.**

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